Lockheed Martin Space Mission Systems & Services
Science, Engineering, Analysis, and Test
2400 NASA Road 1, P.O. Box 58561, Houston, TX 77258-8561
Telephone (281) 333-5411

LOCKHEED MARTIN

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TO: C.H. Lin

VIA: F. F. Jeng *Original Initialed by FFJ*
J. F. Keener *Original Initialed JFK*
A. H. Milliken *Original Initialed by AM*

FROM: W. C. Lee *Original Signed by Win-Chin Lee*

SUBJECT: Interim Report on the Advanced Life Support SMAP Solid Waste Handling Trade Study

The attached interim report covers the status and progress of the study for fiscal year 2000 under STO ECAYS. This report includes assumptions, data collection, preliminary results and issues to be resolved for next fiscal year.

Please address any questions or issues regarding this report to Wen-Ching Lee (281-333-6826).

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INTERIM REPORT

ADVANCED LIFE SUPPORT
SYSTEMS MODELING AND ANALYSIS PROJECT

SOLID WASTE HANDLING TRADE STUDY

Prepared by

Original Signed by Win-Chin Lee

____

Wen-Ching Lee

Approved by

Original Signed by Frank Jeng

____

F. F. Jeng, Lead
Advanced ECS Analysis

Original Signed by John F. Keener

____

J. F. Keener, Project Manager
Thermal and Fluid Process Analysis

Original Signed by Andrew Milliken

____

Andrew H. Milliken, Manager
Thermal Analysis Section

SEPTEMBER 2000

LMSEAT 33488

INTERIM REPORT

ADVANCED LIFE SUPPORT
SYSTEMS MODELING AND ANALYSIS PROJECT

SOLID WASTE HANDLING TRADE STUDY

Prepared by

Lockheed Martin Space Operations
Houston, Texas

Contract NSA9-19100

Prepared for

National Aeronautics and Space Administration
Lyndon B. Johnson Space Center
Houston, Texas

September 2000

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1.0 PURPOSE

The purpose of this study is two fold:

1. Facilitate the technology selection process for solid waste handling technologies.
2. Facilitate the development of Solid Processing System (SPS) in Bio-Plex module

This study was started after the completion of the Waste Processing and Resource Recovery (WPRR) Workshop dated April 3-6 2000. The technological data collected from the workshop were used as primary source to evaluate the performance of each technology.

This interim report is prepared to document the progress and status of the study for FY 2000. It also covers areas that require improvements and updates, which will be continued in the fiscal year 2001.

2.0 ASSUMPTIONS & PREMISES

The following mission data and assumptions are collected from ALS Modeling and Analysis Reference Missions Document (Reference 1) for Mars near term missions:

2.1 Missions : Transit and Independent Exploration Missions – Mars Dual Lander Missions
Reference mission scenarios 1 & 2

2.2 Three vehicles : Transit Vehicle, Descent/Ascent Lander and Habitat Lander

2.3 Mission Durations :
Transit Vehicle : outbound : 180 days, return : 180 days
Descent/Ascent Lander : up to 30 days
Habitat Lander : 600 days

2.4 Solid waste type using ALS technologies :
Transit Vehicle : Food Waste/Trash, Inedible Biomass, Human Waste (feces only)
Descent/Ascent Lander : Food Waste/Trash, Human Waste (feces only), EMU Waste (EMU Diaper)
Habitat Lander : Food Waste/Trash, Inedible Biomass, Human Waste (feces only) , EMU Waste (EMU Diaper)

2.5 Environments :
Transit Vehicle : Vacuum & zero gravity (0 g)
Descent/Ascent Lander : Vacuum/micro atmosphere (0.01 atm) & micro gravity (0-0.38 g)
Habitat Lander : Micro atmosphere (0.01 atm) & micro gravity (0.38 g)

3.0 STUDY METHODOLOGY

In Mars near term missions, plant growth requirement for food supply will be up to 15-30 percent of the total food requirement (Reference 2). The amount of carbon dioxide (CO_2) generated by crew may be enough for plant growth. The carbon content in inedible biomass may not require to be recovered for the missions. However, water content in inedible biomass or any trash will need to be recovered. Therefore, lyophilization technology is selected as the prime candidate in order to recover water from wastes.

The incineration technology is also selected because it is the most mature and popular technology. Data for incineration are available and can be useful for technology comparison.

After discussion with members of the SMAP society, the storage and warm air drying technologies were also selected as potential candidates. As a result, the following technologies/options are included in this trade study:

- Storage
- Warm Air Drying – Recover water
- Incineration- Recover CO_2 & Water
  - Continuous
  - Batch
- Lyophilization – Recover water

Pyrolysis may be added to the list in the future.

The study focuses on comparing the following requirements for each selected technology:

- Mass
- Volume
- Power

In addition, issues associated with each technology in the following areas will also be addressed when applicable:

- Storage – feeds and products
- Waste stabilization/sanitation
- Resource recovery
- Feed preparation
- Continuous/Batch process
- End products

4.0 TECHNICAL DATA COLLECTION/MODIFICATION

The first step of this study is to collect technical data. Since there are so many technologies included in the study, the data collection effort is quite extensive. This section summarizes requirements and results of data collection efforts.

Data required to perform the trade study include the following groups:

Mission definition and assumptions
Solid waste model for Mars near term missions
Technical data of each selected technology
Physical properties of each type of wastes

The result of data collection effort for each group is summarized as below:

4.1 Mission definition and assumptions

See Section 2 - Assumptions and Premises.

4.2 Solid waste model for Mars near term missions

The solid waste model for Mars near term missions has been defined in ‘Reference Mission and Waste Model Document’ of the WPRR workshop (Reference 2). Table 1 summarizes details of the waste model for a crew of six.

After the WPRR workshop, data listed in Table 1were criticized and challenged. These data have been revised to include the following improvements:

A. The waste rates for urine/shower/hand wash were excluded from the waste model since they will be handled by waste water system per Reference 1.
B. The data of inedible biomass in Table 1 were listed as dry basis. Comments from members of the SMAP society suggested that the water content for biomass should be included in the waste model. The water content of inedible biomass was then estimated using plant data received from Dan Barta of JSC (Reference 4). The calculation showed that 90% of the biomass could be water. As a result, the total inedible biomass rate was increased by 900%.
C. Alan Drysdale of KSC Boeing provided comments on the trash rate. His comments stated that waste data collected from recent shuttle missions STS-99 & STS-101 should be used as baseline for studies in mission impacts of waste. The trash data for these two shuttle missions were received from Sabrina Maxwell/Boeing (Reference 8) and were reviewed, with the intention of possibly using these data for updating the waste model. The results of this review are included in Tables 2A & 2B.
D. Table 2A includes detail trash data breakdown for STS-99/101 missions. It also includes breakdowns from WPRR workshop model for comparison. From this table, it indicates that the total trash flow excluding unused drinks for STS-99/101 are fairly close (1.173Kg/crew/day vs. 1.088 Kg/crew/day), although the rate for individual trash type varies in a wide range (for example, the rate for packaging material for mission STS-99 is 0.0933 Kg/crew/day while that for mission STS-101 is only 0.0147 Kg/crew/day).
E. From Table 2A, it also shows that the total trash rate excluding drinks for WPRR workshop model is much higher than those of STS-99/101 missions. It was found that the data for STS missions contains minimum data of paper and filters. If the paper and filters data are added, the total rates for these missions are basically the same as that of WPRR work shop data, as shown in Table 2B. Therefore, it is decided that the trash rate in Table 1 is compatible to data from STS-99/101 missions.
F. The data for used maximum absorbency garment (MAG), EMU diaper, were collected as 0.175 Kg/MAG and 0.55 Kg/EMU urine collection. The EMU waste is included in the solid waste model.
G. Unused drinks for STS missions range from 0.301Kg/day to 1.16 Kg/day per crew (Table 2A). This data is much higher than the 0.128 Kg/day/crew used in Table 1.

Table 3 summarizes the revised waste rates, which will be used as the waste model in this trade study. The unused drink rate is excluded as it will be handle by the waste water system.

4.3 Technical Data of each selected technology

A. Lyophilization

The mass, volume and power (MVP) requirement for the lyophilization unit has been estimated by Eric Litwiller/Stanford University and has been received from Mike Flynn/ARC(Reference 6). This system is designed to handle human waste of 1.9Kg/day for a cycle time of three days. Table 4 contains detail of the estimates.

B. Incineration

Table 5 summarizes MVP estimates for the continuous incineration process using data from work sheets of WPRR workshop. The work sheets for batch incineration process contain minimum data. These work sheets were developed during the workshop and were based on dry inedible biomass rates for Mars reference mission scenario 3.

C. Warm Air Drying

The vendor data from SHELLAB were collected and summarized in Table 6. These data will be used to estimate MVP requirement for dryers.

D. Storage

Density data for various trash data were collected. See section 4.D for details.

4.4 Physical properties of each type of wastes

The following density data were collected from various sources and were tabulated as below:

A. Table 7 - Density for trash storage. Estimated from ISS trash management data (Reference 7)

B. Table 8 - Trash Density data from shuttle missions STS-99 & STS-101 (Reference 8)

C. Table 9 - Density of wet inedible biomass, estimated using data collected from Dr. John A. Hogan (Reference 9).

D. Density for dry feces powder – Estimated from Table 7-4 of reference 10 as 35-40 lb/ft3 (560-640 Kg/m3)

5.0 PRELIMINARY RESULTS

This section summarizes the preliminary findings of this study for FY 2000:

5.1 Storage Concept

This option assumes no waste compaction and no waste processing. Solid wastes are collected, packed and sent for storage. Density data collected and estimated are used to determine volume requirement for each mission. Table 10 A/B contain volume requirements for the two mission scenarios

5.2 Drying/Dryer Design Concept

This is the option with the intention of recovering as much water as possible from wastes. The human wastes (feces and urine) are deemed not suitable to this option. The design concept of this option are described as below :

A. Separate dry trash from wet trash and dispose them in different bags during daily operation. Collect food waste and wet tissues in wet trash bags; and collect paper, filter, plastics and tapes in the dry trash bags. This is the most important step for the success of this option.
B. Collect unused drinks in Waste Water tanks. Don't pour unused drinks in any trash bag. Collect drink containers/pouches in wet trash bags.
C. Human wastes (Feces & EMU diapers) are handled by lyophilization. Urine is collected and sent to bioreactor feed tank.
D. Design large dryers for handling inedible biomass and small dryers for food waste and wet trash dehydration.
E. Shredder is required for drying process.
F. Include filter as part of the dryer design to remove odor released from the waste drying process.

Large Dryer Design - From Table 3, it is shown that 55-66% solid waste rate is inedible biomass. Among the inedible biomass, the highest percentage crop is from wheat. From crop data of the Baseline Values and Assumption Document (BVAD, Reference 11), it is estimated that the inedible biomass rate (wet basis) from wheat is 19.8kg/day for a crew size of six. The total inedible biomass from wheat for staging duration of 40 days can be 792 kg per harvest. The dryer is designed to handle 200 kg inedible biomass per batch operation with the operation duration of 48 to 72 hours. The details of the design are included in Table 11. A total of two large dryer units are adequate for the application.

Small Dryer Design - The dryer designed to handle wet trash or waste food is estimated to remove 1.0 kg water for each batch operation. A total of three small dryers are required with two dryers operating daily and one in spare. The SHELLAB Model 1330FX oven should be adequate.

5.3 Incineration Design Concept

The solid waste model for incineration technology includes:

Transit Vehicle : Food Waste/Trash, Inedible Biomass, Feces
Habitat Lander : Food Waste/Trash, Inedible Biomass, Feces & EMU waste

The reference mission scenarios 1 & 2 were selected for this study. The proposed feeds, which include moisture content of inedible biomass, for incineration unit were forwarded to JoAnn Lighty and Kevin Davis for their advices of estimating mass, volume and power requirement. The impact of the wet feeds to heater duty requirement, combustion temperature and heat released during the incineration process should be addressed.

Table 12 A/B contain the proposed feeds for the incineration technology. The average feed rate for a continuous incineration system varies from 1.16 to 1.26 kg/hr. It is estimated that the current design from University of Utah should be capable of handling the proposed feeds.

5.4 Lyophilization Design Concept

The worksheet obtained from WPRR workshop contains minimal data. The progress report of Lyophilization technology (Reference 5) provides the most current design details of the unit. However, there is no test data of any solid waste in the progress report. The MVP data have been estimated and provided by Litwiller/Flynn (Reference 6). The design flow for the unit used in Mars application is listed as below:

A. Feces (0.12 Kg/person/day – 0.03 Kg solid & 0.09 Kg liquid) per Reference 3
   & Toilet paper (0.0051-0.0411 Kg/day) from Reference 12
B. EMU waste (0.55 Kg/EMU urine plus 0.175 Kg diaper)
C. Brine solution from Vapor Phase Catalytic Ammonia Reactor (VPCAR): Rate – 2% of urine rate

It is estimated that the human waste will be processed daily. A minimum of three lyophilzation units are required. The fourth unit may be required as spare.

6.0 ISSUES TO BE RESOLVED

This study has been started in June 2000 after the completion of the WPRR workshop. Due to limited data collected during the workshop and the minimum test data available, the study cannot be completed. The following questions and issues require either answers or improvements/updates in the next fiscal year:

6.1. Fundamental issues of Lyophilization:

A. Can the Lyophilization process handle trash, paper, or packaging materials?
The progress report of lyophilization unit stated that the focus of the unit development is aimed to design a system that can be applicable to the following solid wastes: human wastes, food wastes, general trash and water treatment system by products. The answer to the question of whether the unit can be used to handle waste other than human feces is still unknown. Some experimental work is definitely required.

B. Can the unit function properly in Mars micro-atmospheric environment?
The fact is that the presence of micro atmospheric on Mars surface may have impact on the lyophilization process.

6.2 Estimate of bulk density of inedible biomass
The bulk density for wet inedible biomass was estimated using four crop (soybean, wheat, tomato and potato) data provided by Dr. John Hogan. This density can be better estimated if more data become available.

6.3 Impact to incineration due to high moisture content feed
The high water content in wet inedible biomass is expected to have impact on the performance of the incinerator. The extent of the impact remains to be investigated.

Other related issue is the option of using dryers as preprocessor of incinerator to remove moisture from wet biomass. The removal of moisture will not only reduce the incinerator throughput and therefore reduce the incinerator size, but also lower the temperature level for moisture recovery and reduce condenser duty. This option should be considered in the next fiscal year.

6.4 Batch incineration system
The batch incineration system is untouched in this study due to lack of data. This option should not be excluded due to the fact that the proposed feed rate may be too low for a continuous operation, and the batch operation may be better if the MVP requirement is not too high.

6.5 Waste Stabilization/Sterilization – What are the best methods other than drying?
This is the area that requires attention from experts of biologically active materials handling. The drying process is considered as the first step for waste stabilization. Basic research is necessary in order to determine other reliable waste sterilization processes.

6.6 Inedible biomass rate
The inedible biomass rates in the workshop were estimated based on data from BVAD (Reference 11) and assumed percentage of food grown. These rates may be better estimated by using other crop simulation software.

6.7 Unused drink rate
Per Table 2A, the unused drink rate for STS missions varies from 0.301 to 1.16 Kg/day. The value used in WPRR workshop for drink waste is 0.128 Kg/day, which is lower than these STS values. More data or studies are needed in order to determine an acceptable value for waste water processing.

REFERENCES

1. Linda Jeng & Mike Ewert, Advanced Life Support Systems Modeling and Analysis Reference Missions Document, May 2000, JSC-39502.
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3. M.A.Golub & T.Wydeven, Waste Streams in a Crewed Space Habitat II, Waste Management & Research (1992), **10**, 269-280.
4. Plant data collected from Dr. Dan Barta of JSC and summarized by Tony Hanford, 1998
5. Eric Litwiller & Mike Flynn, Lyophilization Progress Report (Feb. – July 2000)
6. Eric Litwiller & Mike Flynn, Estimates of mass and volume for Lyophilization unit, August 30, 2000.
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8. Sabrina Maxwell S., Waste Stream Analysis for STS as applied to Mars Missions, ILSBS Conference, 2000, Baltimore.
9. Personal Communication, John A. Hogan, Rutgers – The State University of New Jersey, Sept 14, 2000.
10. Page 7-5 of Perry Handbook (Fifth Edition) – Table 7-4 Material Classes and Weights
11. Baseline Values and Assumption Document (BVAD), JSC 39317, CTSD-ADV-371, June 1999.
12. T. Wydeven and Morton Golub, Generation Rates and Chemical Compositions of Waste Streams in A Typical Crewed Space Habitat, NASA Technical Memorandum 102799, August 1990.

Table 1 - Solid Waste Model from WPRR Workshop - Units are Kg/day (based on 6 person crew)

Waste Component	Transit, All Packaged Food	Independent Exploration, salad crops grown	Exploration Mission, Low carbohydrate diet	Extended Base, All plants menu	Extended Base, All plants menu
Dry Human Waste	0.720	0.720	0.720	0.720	0.720
Inedible Plant Biomass (1)	1.691	2.247	5.450	7.503	13.820
Trash	0.556	0.556	0.556	0.556	0.556
Packaging Material (2)	7.908	4.721	2.017	1.493	0.408
Paper	1.164	1.164	1.164	1.164	1.164
Tape	0.246	0.246	0.246	0.246	0.246
Filters	0.326	0.326	0.326	0.326	0.326
Miscellaneous	0.069	0.069	0.069	0.069	0.069
Total	**12.68**	**10.05**	**10.55**	**12.08**	**17.31**
Grown food	1.860	5.580	18.600	20.700	39.120
Packaged food	11.760	7.020	3.000	2.220	0.606
Mission Duration	180 days	600 days	600 days	10 years	10 years
Grown food (%) (3)	0	10	26	45	85
Packaged food (%)	100	90	74	55	15

ISS data is calculated to 3.3 Kg/day-person, based on 113 days between 5A and 6A with total trash generated of 73
Reference:ISS TRASH OPERATIONS PLAN, 11/4/99, Rodney Brown/JSC

Notes:

(1) Inedible plant biomass is calculated from the BVAD diet Inedible biomass/Average consumption x mass of grow
and adding 10% of packaged food.

(2) Packaging material was calculated by taking the ratio of packaging material to packaged food for the transit mis
then multiply the packaged food for each of the other missions by this ratio.

(2a) The packaging material in the "All crop model" is assumed to be for an all packaged diet.
(The transit mission was assumed to represent the "All crop" waste model)

Table 2A - STS 99/101 Missions Trash Analysis

The following contains trash data detail breakdowns for STS-99 & STS-101 missions

Items	STS-99 Kg/p/day Without Drinks	STS-99 Kg/p/day With Drinks		STS-101 Kg/p/day Without Drinks	STS-101 Kg/p/day With Drinks		WPRR W Kg/p/day Without Drinks
Drinks		1.1611			0.301		
Food	0.1588	0.1588	PM	0.368	0.368	PM	
Food Bag Package				0.528	0.528	PM	
Packaging Material	0.0933	0.0933	PM	0.0147	0.0147	PM	
Plastic Bag				0.0187	0.0187	PM	
Drink Container				0.0014	0.0014	PM	
Tape	0.1229	0.1229	Tape	0.019	0.019	Tape	
Wet Trash	0.4685	0.4685	Trash				
Trash				0.0212	0.0212	Trash	
Wet Towel				0.0469	0.0469	Trash	
Paper							
Battery	0.0458	0.0458	Battery	0.0698	0.0698	Battery	
Filters							
Misc.							
Others	0.2836	0.2836	PM				
Total	1.1729	2.334		1.0877	1.3887		

Table 2B - STS-99/101 Missions Trash Analysis - Including Paper & Filters Data from WPRR Workshop

The following contains trash data detail breakdowns for STS-99 & STS-101 missions

Items	STS-99 Kg/p/day Without Drinks	STS-99 Kg/p/day With Drinks		STS-101 Kg/p/day Without Drinks	STS-101 Kg/p/day With Drinks		WPRR Wo Kg/p/day Without Drinks
Drinks		1.1611			0.301		
Food	0.1588	0.1588	PM	0.368	0.368	PM	
Food Bag Package				0.528	0.528	PM	
Packaging Material	0.0933	0.0933	PM	0.0147	0.0147	PM	
Plastic Bag				0.0187	0.0187	PM	
Drink Container				0.0014	0.0014	PM	
Tape	0.1229	0.1229	Tape	0.019	0.019	Tape	
Wet Trash	0.4685	0.4685	Trash				
Trash				0.0212	0.0212	Trash	
Wet Towel				0.0469	0.0469	Trash	
Paper	0.194			0.194			
Battery	0.0458	0.0458	Battery	0.0698	0.0698	Battery	
Filters	0.0544			0.0544			
Misc.							
Others	0.2836	0.2836	PM				
Total	1.4213	2.334		1.3361	1.3887		

Table 3 - Revised Solid Waste Model Including Water Content in Inedible Biomass

	Mission Vehicle :		**Transit**		**Mission Vehicle :**		**Ha**
	Mission Duration (Days):			**180**	**Mission Duration (Days)**		
Solid Waste Type	Waste Rates (Kg/6 crew/day)				Waste Rates (Kg/6 crew/d		
Human Waste (Note 3)	Sum	Solid	Liquid	Toilet Paper	Sum	Solid	Li
	0.858	0.18	0.54	0.138	0.858	0.18	(
Inedible Biomass	Sum	Dry Mass	Water		Sum	Dry Mass	W
	16.91	1.691	15.219		22.47	2.247	2(
Trash (Note 1)	0.4176				0.4176		
Packing Material (Note 2)	7.308				4.361		
Drinks	0				0		
Food Remains	0.6				0.36		
Paper	1.164				1.164		
Tape	0.246				0.246		
Filters	0.326				0.326		
Misc. Waste	0.069				0.069		
Total	27.8986				30.2716		
EMU waste	EVA/Week		Contingency		EVA/Week		
		Diaper Kg	Urine Kg/EVA/crew			Diaper Kg	Ur Kg
		0.175	0.55			0.175	

Notes:
1. Exclude toilet paper.
2. Explude food remains
3. Feces only, Urine is collected and handled by waste water tank

Table 4 - Mass, Volume & Power Estimates for Lyophilization Unit

Data included in this Table were estimated by Eric Litwiller of Stanford University

Design Basis :

Flow Rate, Kg/day		1.9	(Water Content 1.34 Kg)
Cycle Time (Day)		3	
Influent Density (Kg/m3)		240	
Collection Container Size	12"*12"*18"		
Crew Time Required per Cycle, Hr		0.5	

Lyophilization Unit

Mass, Kg		20		
Volume, M3		0.25		
Thermal Electric Power	Heat Sink Temperature, Deg. F		Energy W hr/Kg water	Average Power @1.: Watts
		40	1100	62
		65	1700	95
		75	2100	116

Vacuum Pump

Mass, Kg	15
Volume, M3	0.03
Power, Watts	200

Table 5 - Mass, Volume & Power Estimates for Incineration Unit - Data Acquired from WPRR workshop (April 4-6, 2000)

Design Basis :

Flow Rate, Kg/hr Less than 5.0 (a few kg/hr per WPRR workshop data)

Incineration Unit - Continuous Thermal/Catalytic Incineration

Major Component Item	Mass Kg	Volume M3	Power Kw	Heat released Kw
Knife Mill	65	0.366	1.5	0.2
Dry Feeder	40	0.852	0.746	0.12
Wet Feeder	34		0.519	0.1
Incinerator	41	1.78	<2	6
Gas Cleanup Equipment	123	1.53	1.8	0.7

Incineration Unit - Batch Incineration

Major Component Item	Mass Kg	Volume M3	Power Kw	Heat released Kw
Knife Mill	<65	<0.4	<1.5	
Dry Feeder	TBD	TBD	TBD	TBD
Wet Feeder	TBD	TBD	TBD	TBD
Incinerator	TBD	TBD	TBD	TBD
Gas Cleanup Equipment	TBD	TBD	TBD	TBD

Table 6 - Mass, Volume & Power Estimates for Dryer Unit - Data Acquired from SHELLAB Laboratory ovens

Dryer Unit

	SHELLAB Model No.						
	1670	1675	1680	1685	1690	1330FX	1350FX
Style	CounterTop	Floor	Floor with Double Door	Floor	Floor with Double Door	CounterTop	CounterTop
System	Forced Air By Fan	Forced Air By Fan	Forced Air By Fan	Forced Air By Fan	Forced Air By Fan	Forced Air By Fan	Forced Air By Fan
Mass, Kg	75	168	223	264	377	72.5	97.5
Volume, M3	0.567	1.193	1.504	1.934	3.464	0.220	0.314
Chamber Capacity, liters	124.64	294.97	413.03	885.38	1505.47	41.31	116.99
Power, Watts	3000	5500	5500	11000	10500	1650	2000
Exterior Dimension,CM							
High	99.1	144.8	144.8	210.9	203.2	77.5	80
Depth	69.25	73.7	69.3	83.9	83.9	53.3	58.4
Width	82.6	111.8	149.9	109.3	203.2	53.3	67.3
Exterior Volume, Liter	566.86	1193.10	1504.19	1934.01	3464.25	220.17	314.43
Interior Dimension,CM							
High	48.3	76.2	76.2	171.5	137.2	36.5	47
Depth	50.8	50.8	50.8	63.5	63.5	34.3	46.7
Width	50.8	76.2	106.7	81.3	172.8	33	53.3
Interior Volume, Liter	124.64	294.97	413.03	885.38	1505.47	41.31	116.99

Table 7 - Density for trash storage

This spread sheet calculates average trash densities for all proposed ISS flights

Flight No	Total Volume, Cu. Ft.	Total Wt., Kg	Calculated Density, Kg/M3	
2P	68.94	594.8	304.6905	Note
3P	56.26	487.9	306.26	Note
4P	145.27	1262.6	306.9369	Note
5P	120.5	1046	306.5518	Note
6P	107.89	920.8	301.4001	Note
7P	120.5	1032	302.4488	Note
3A	6	57	335.4925	Note
4A	2	19	335.4925	Note
5A	2	19	335.4925	Note
5A.1	0.1	0	0	Note
6A	0.1	0	0	Note
7A	10	90	317.835	Note
7A.1	0.1	0	0	Note
Average			315.2601	

Table 8 - Trash Density Data from Shuttle Missions STS-99/101

The following are density data that were calculated from the collected STS-99 & STS-101 trash dat

Item	Density, Kg/m3	Average density, Kg/
Food Waste	490	
Food Bags	285-715	410
Food Package (Exclusive Food)	345-385	
Drink (Partially Used)	160-860	310
Drink (Unused)	1000	
Dry Trash with Drink	286-390	
Dry Trash w/o Drink	250-270	
Wet Trash	180-620	345
Toilet Item	170-500	300
Urine Bag	600	
MAG	158-230	
Wet Towel	400-560	
Tape	180-540	260
Plastic Bag	36-131	
Other	70-360	190

Table 9 - Density of Wet Inedible Biomass

Estimate inedible biomass density for carbohydrate crops

	Ined. Biomass Kg/person/day - Dry	Moisture Content % (Note)	Ined. Biomass Kg/person/day - Wet	Packed Mat'l Wet Density g/l (Note)	Packed M Volume (
Soybean	0	77.2	0	181	
Wheat	0.33	73.4	1.240602	146	8.49727
White Potato	0.073	86.5	0.540741	222	2.43576
Sweet Potato	0.077	86.5	0.57037	222	2.56923
Rice	0	73.4	0	146	
Peanut	0	77.2	0	181	
Tomato	0.228	81	1.2	183	6.55737
	0.708		3.551713		20.0596

Average Density for wet inedible biomass (Kg/M3) = 177.057

Estimate inedible biomass density for all crops

	Ined. Biomass Kg/person/day - Dry	Moisture Content %	Ined. Biomass Kg/person/day - Wet	Packed Mat'l Wet Density g/l	Packed M Volume (
Soybean	0.146	77.2	0.640351	181	3.5378
Wheat	0.36	73.4	1.353383	146	9.2697
White Potato	0.086	86.5	0.637037	222	2.86953
Sweet Potato	0.086	86.5	0.637037	222	2.86953
Rice	0.044	73.4	0.165414	146	1.13296
Peanut	0.035	77.2	0.153509	181	0.84811
Tomato	0.238	81	1.252632	183	6.84498
	0.995		4.839362		27.3727

Average Density for wet inedible biomass (Kg/M3) = 176.79

Note : Moisture content and density for each crop are obtained from John A. Hogan (Rutgers - The State Univ. of Ne

Table 10A - Storage Volume Requirement of Solid Waste for Mars Near Term Mission - Scenerio 1

This spread sheet calculates the storage volume requirement (M3) for Mars near term mission

Mission Vehicle : **Transit** **Mission Duration (Days):** **180**

Solid Waste Type	Waste Rates (Kg/6 crew/day)						
Human Waste (Note 3)	Sum	Solid	Liquid	Toilet Paper			
	0.858	0.18	0.54	0.138			
Inedible Biomass	Sum	Protein	Carbo.	Lipids	Fiber	Lignin	Water
	16.9099	0.23615	0.26988	0.06747	1.01629	0.1012	15.21
Trash (Note 1)	0.4176						
Packing Material (Note 2)	7.308						
Drinks	0						
Food Remains	0.6						
Paper	1.164						
Tape	0.246						
Filters	0.326						
Misc. Waste	0.069						
Total	27.8985						

EMU waste	EVA/Week		Contingency
		Diaper Kg	Urine Kg/EVA/crew
		0.173	0.55

Notes:
1. Exclude toilet paper.
2. Explude food remains
3. Feces only
4. Data estimated from "ISS Trash Management Status", p. 11 (1999)
5. Data estimated from Table 9 of this report

Table 10B - Storage Volume Requirement of Solid Waste for Mars Near Term Mission - Scenerio 2

This spread sheet calculates the storage volume requirement (M3) for Mars near term mission

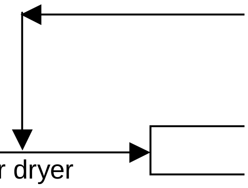
Mission Vehicle : Habitat **Mission Duration (Days):** **600**

Solid Waste Type	Waste Rates (Kg/6 crew/day)						
Human Waste (Note 3)	Sum	Solid	Liquid	Toilet Paper			
	0.858	0.18	0.54	0.138			
Inedible Biomass	Sum	Protein	Carbo.	Lipids	Fiber	Lignin	Water
	22.47	0.3138	0.3586	0.0897	1.3504	0.1345	20.2
Trash (Note 1)	0.4176						
Packing Material (Note 2)	4.361						
Drinks	0						
Food Remains	0.36						
Paper	1.164						
Tape	0.246						
Filters	0.326						
Misc. Waste	0.069						
Total	30.2716						

EMU waste	EVA/Week		10
		Diaper Kg	Urine Kg/EVA/crew
		0.173	0.55

Notes:
1. Exclude toilet paper.
2. Explude food remains
3. Feces only
4. Data estimated from "ISS Trash Management Status", p. 11 (1999)
5. Data estimated from Table 9 of this report

Table 11 - Detail Dryer Design for handling Inedible Biomass



This spread sheet performs calculations for dryer sizing
CASE : Inedible Biomass

Inedible Biomass, lb	440	Processed by warm air dryer

Fresh Ai

Room Air condition (point 1): Air entering dryer/after preheater (point 3)

Pressure (psia)	14.7	Pressure (psia)
Temperature (Deg F):	75	Temperature (Deg F):
Relative Humidity (%):	60	Wet Bulb (Deg F):

The following calculation determine the air flow and preheater duty requirements for the dryer :
The calculation steps are copied from example 7, page 12-11 of Perry Handbook (5th Edition).

Moisture removal rate (lb/hr):	8.25	Process
Humidity of air at dryer inlet H1 (lb H2O/lb dry air):	0.0113	input per
Humidity of air entering dryer H3 (lb H2O/lb dry air):	0.0492	input per
Humidity of air leaving dryer H4 (lb H2O/lb dry air):	0.0544	input per
Specific volume of air at dryer inlet V3 (cu.ft./lb dry air):	16.6	input per
Enthalpy of room air h1 (BTU/lb dry air):	30.12	input per
Enthalpy of air entering dryer h3 (BTU/lb dry air):	91.6	input per
Enthalpy of air leaving dryer h4 (BTU/lb dry air):	91.9	input per
Quantity of dry air required (lb/hr):	1586.538	
Air flow rate at dryer inlet (CFM):	438.9423	
Calculate fresh air rate (lb/hr):	191.4153	
Calculate recirculated air rate (lb/hr):	1395.123	
Calculate air preheater heat load (BTU/hr):	11349.68	
Calculate air preheater heat load (watts):	3326.59	
Fan BHP :	1.062956	Assume
Fan Watts:	792.6462	
Minimum Dryer Internal Volume (m3) =	1.129944	Using De
Minimum Dryer Internal Volume (m3) =	0.561798	Using De

The following oven is selected per data from Table 6 of this report. The oven is selected to meet the minimum dryer

Model	SHELLAB 1685 (for shredded material)
Mass, Kg	264
Exterior Volume, M3	1.93

Internal Volume, M3	0.885
Power (Watts)	11000

Table 12A - Feed for Incineration Process - Scenario 1

This spread sheet contains waste feed to incinerator for Mars near term mission

Mission Vehicle :	**Transit (Scenario 1)**	**Mission Duration (Days):**	**18**

Solid Waste Type	Waste Rates (Kg/6 crew/day)						
Human Waste (Note 3)	Sum	Solid	Liquid	Toilet Paper			
	0.858	0.18	0.54	0.138			
Inedible Biomass	Sum	Protein	Carbo.	Lipids	Fiber	Lignin	Water
	16.9099	0.23615	0.26988	0.06747	1.01629	0.1012	15.2189
Trash (Note 1)	0.4176						
Packing Material (Note 2)	7.308						
Drinks	0						
Food Remains	0.6						
Paper	1.164						
Tape	0.246						
Filters	0.326						
Misc. Waste	0.069						
Total	27.8985						

EMU waste	EVA/Week	Contingency
	Diaper Kg	Urine Kg/EVA/crew
	0.173	0.55

Notes:
1. Exclude toilet paper.
2. Exclude food remains
3. Feces only

Table 12B - Feed for Incineration Process - Scenario 2

This spread sheet contains waste feed to incinerator for Mars near term mission

Mission Vehicle : **Habitat (Scenario 2)** **Mission Duration (Days):**

Solid Waste Type	Waste Rates (Kg/6 crew/day)						
Human Waste (Note 3)	Sum	Solid	Liquid	Toilet Paper			
	0.858	0.18	0.54	0.138			
Inedible Biomass	Sum	Protein	Carbo.	Lipids	Fiber	Lignin	Wat
	22.47	0.3138	0.3586	0.0897	1.3504	0.1345	20.
Trash (Note 1)	0.4176						
Packing Material (Note 2)	4.361						
Drinks	0						
Food Remains	0.36						
Paper	1.164						
Tape	0.246						
Filters	0.326						
Misc. Waste	0.069						
Total	30.2716						

EMU waste	EVA/Week		10
		Diaper Kg	Urine Kg/EVA/crew
		0.173	0.55

Notes:
1. Exclude toilet paper.
2. Exclude food remains
3. Feces only